UK transport decoupling: On track for clean growth in transport?

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UK Transport Decoupling: On Track for Clean Growth in Transport?

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1. Introduction

Climate change presents a clear and immediate threat to the planet, necessitating effective policy to limit environmental damage (Intergovernmental Panel on Climate Change (IPCC), 2015). As a result, there is debate over whether economic growth can be sustainable (Tienhaara, 2014). The current economic and political system relies on continuous growth, which can exacerbate unsustainable elements of the economy (Næss and Høyer, 2009). However, within policy-making and non-academic research institutions, there is general agreement that this can be achieved through sustainable development or ‘green’ growth (United Nations Environment Program (UNEP), 2011; Organisation for Economic Co-operation and Development (OECD), 2011). This theory’s importance is highlighted by the UN’s key agenda, the sustainable development goals (UN, 2015a). Decoupling, defined as separating environmental pressure or ‘bads’ and economic ‘goods’, is often employed as a concept to make explicit the implicit goal of sustainable development (OECD, 2002). Green growth is based on the idea of growth-based decoupling (Martínez-Alier, 2010). This green growth is often evaluated through decoupling analysis, which creates a quantitative ‘indicator’ or ‘index’ to show the extent of decoupling.

In academia, there is a body of literature critical on economic growth, arguing that steady-state or degrowth economies can still ensure prosperity, using different measures from gross domestic product (GDP), such as human development indicators (Jackson, 2009; Pacheco *et al.,* 2018). This literature argues that policy research, defined here as policy-focussed practitioner (‘grey’) literature from institutions such as governmental, inter-governmental and NGO bodies is flawed. They are critiqued for being overly-optimistic about technological improvement, using older decoupling analysis methods and specific variables, such as production-based emissions, which produce more positive results to promote the current socio-economic order and their commitment to growth (Alexander *at al*., 2018; Peters and Hertwich, 2008; Fletcher and Rammelt, 2017). It is therefore important to study sustainability in the context of this growth-orientated paradigm, which is questioned in the academic literature whilst policy research often assumes growth (Dryzek, 2013,147-155).

Transport is the largest emitter of greenhouse gases in the UK at 27%, according to government statistics tracking domestic emissions, making the real picture with international emissions even higher (BEIS, 2018; Committee on Climate Change (CCC), 2013) (Figure 1.1). However, continued use of transport is vital, not only for everyday mobility; to take part in an increasingly globalised world, goods and people must move internationally (International Transport Forum (ITF), 2017). Transport decoupling is therefore essential to ensure both sustainability and participation in the global economy whilst maintaining growth. However, when faced with decisions between economic and environmental benefits, transport policy has increasingly pursued economic targets (Goulden *et al.,* 2014). This is despite claims from governments since New Labour, in power from 1997-2010, that transport would enter a more sustainable 'new realist' paradigm, where sustainability targets would be integrated into transport to replace 'predict and provide' policy which focussed on projecting and meeting demand, usually with road infrastructure (Goodwin, 1999; Docherty and Shaw, 2008).

For UK transport, few decoupling studies between environmental and economic variables have been conducted. For example, Goulden *et al*. (2014) found a lack of absolute decoupling. However, this was an atheoretical examination of trends, which simply took domestic transport emissions and showed their change in percentage terms over time alongside GDP. There was no consideration of the types of variables used, for example whether domestic transport emissions properly capture the footprint of UK activity. Furthermore, there is no discussion or use of the full breadth of methodological literature for decoupling analysis (Goulden *et al.,* 2014). The lack of focus is likely due to the decoupling analysis being conducted to supplement a wider study on the state of transport policy, leaving a gap for more focussed decoupling analysis (Goulden *et al.,* 2014).

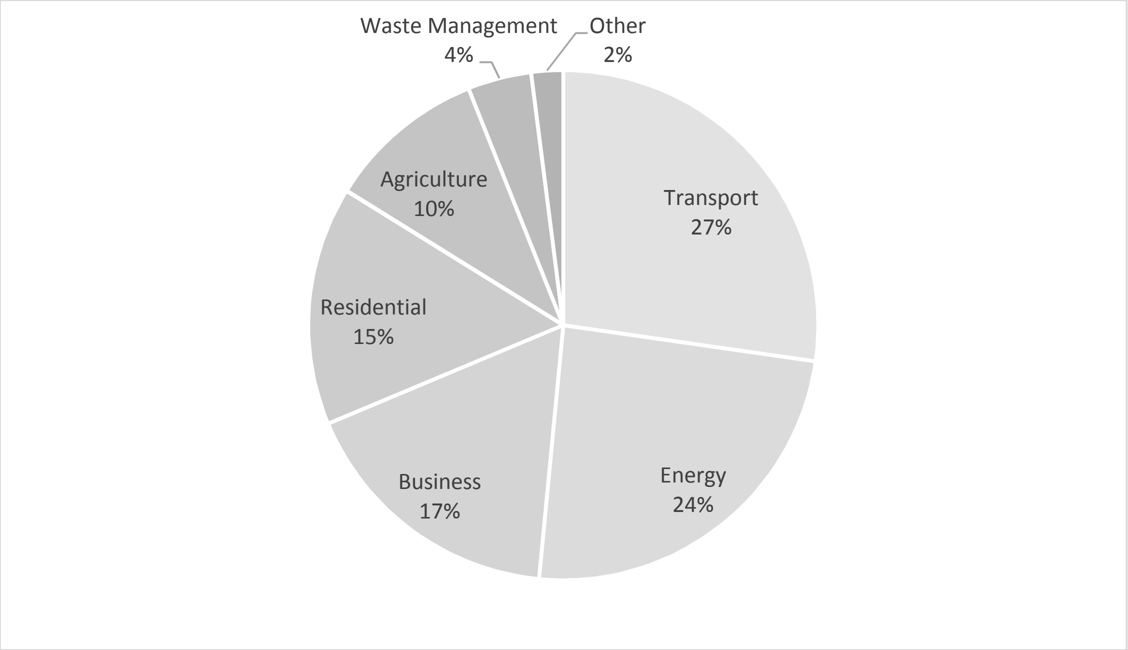

Figure 1: UK sector greenhouse gas emissions 2016 (BEIS, 2019)

This paper reflects the current misalignment in the literature between academic and policy-focussed practitioner research, both in terms of methodological approaches adopted and the conclusions reached with regards to decoupling within the paradigm of sustainable development. The research question for this paper is: to what extent is decoupling between transport output growth and emissions present in the UK from 1997-2015? To address this misalignment within the context of the research question, this paper created an innovative decoupling analysis methodology which explores the past extent and future viability of decoupling and green growth in UK transport. Several methodological innovations are designed to create an analysis that is policy-oriented and aims to improve its relevance for answering policy research questions, both on transport decoupling and other sectors.

The first element of this policy-oriented research design is an 'axiomatic' index that addresses several methodological issues found in other indexes, whilst including an additional axiom that differentiates absolute and relative decoupling. This distinction is important due to the current emphasis on absolute emissions reductions in sustainable development (OECD 2014). Secondly, a consumption-based emissions inventory[1], as opposed to more standard territorial production-based models, was chosen to properly identify the scale of UK transport emissions and required scope of policy response (Peters and Hertwich 2008). These consumption-based emissions are combined with a consideration of the ‘well-below’ 2OC target of the Paris Agreement (used a ‘planetary boundary’ in the model), placing analysis within context of the macro benchmark for climate policy (Rockström *et al*. 2009). Beyond these central elements, methodological decisions, such as the sectoral scope of study and the use of transport output variables rather than GDP, were motivated by the creation of a policy-oriented research design. Further detail on these choices are provided in sections 2 and 4. However, this paper acknowledges that further research is required to empirically determine the link between academic research and policy outcomes in this area.

Section two outlines the materials and methods, discussing methodological choices and justifying the analytical approach; section three presents the results; section four discusses key trends, the barriers to decoupling in transport and the key methodological findings; section five provides the research conclusions.

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[1] Defined as “consumption equals production-based emissions minus the emissions from the production of exports, plus the emissions from the production of imports” (Barret *et al.* 2013)

2. Materials and Methods

2.1: Methodology

Figure 2 summarises the methodological approach of the research, which adopts the *research process onion* methodological framework of Saunders *et al*. (2016). The framework provides a useful structure to visualise the research design and contribute to improving the transparency and replicability of the overarching methodological approach. Whilst it does not show every possible methodological choice, it demonstrates the main options considered by the researchers.

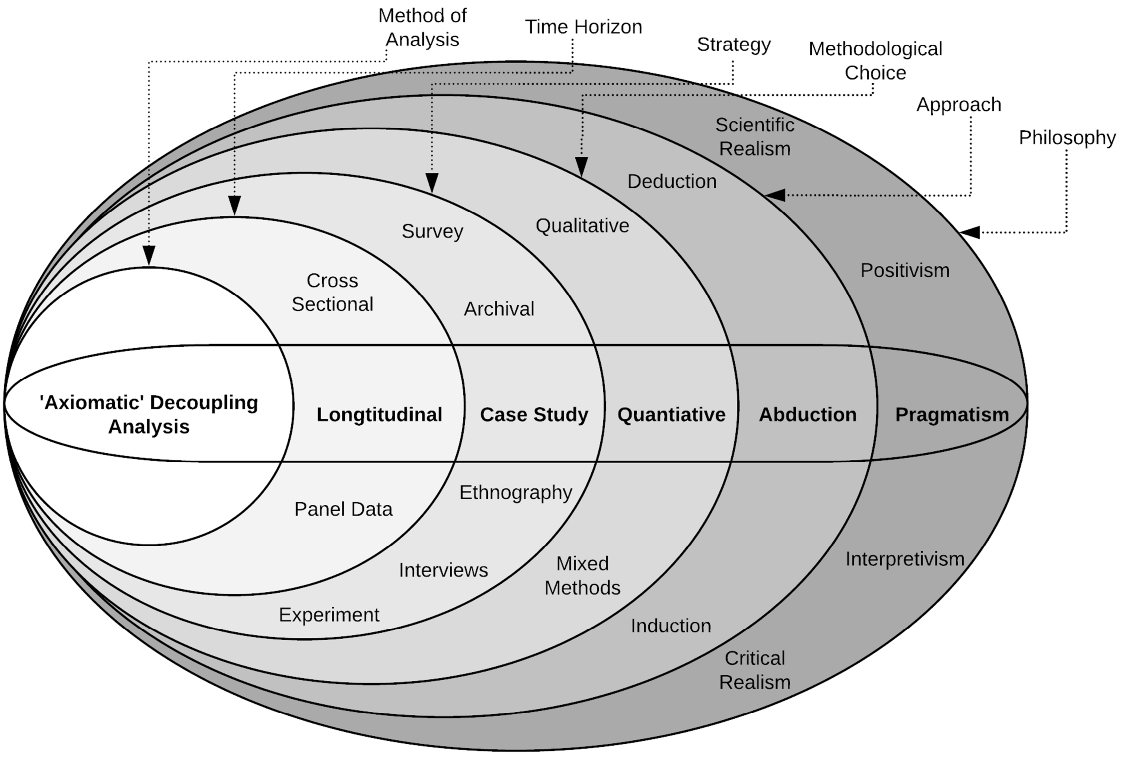

Figure 2: The research design (adapted from Saunders *et al.,* 2016)

This research selected the philosophical position of pragmatism, which focuses on the method and using methods that are well suited to meeting the research aims, rather than claiming ontological superiority, in the sense of best describing ‘what is’ in the world (Morgan, 2007; Warren, 2015). Pragmatism acknowledges philosophical problems with positivist research, such as the assumption of knowledge separated from its context and the often-unrealistic aim of creating ‘naturalist’ research on par with the natural sciences (Johnson, 2006). However, it avoids relativistic views which render the aim of reliability or validity impossible (Friedrichs and Kratochwil, 2009). Instead, what is important is whether or not generated knowledge is accepted as true, reducing epistemological restrictions and making it suitable for a research question that aims to create useful indicators (Almeder, 2007). Valid and reliable measurement remains a justifiable goal, whilst acknowledging problems with generating this form of knowledge and creating space for reflexivity. This also reflects the fact that policy-focussed practitioner research is not concerned with ontological and epistemological discussions.

This study adopts an abductive approach, as it reflects the observation that research is often a continual process of moving between theory and data to provide the best explanations (Morgan, 2007). This study uses existing knowledge on decoupling and sustainable development but without testing hypotheses, as it is unclear what the extent of decoupling is likely to be, given the mixed results in the literature. Data is, therefore, not collected in an atheoretical vacuum but with a theoretical framework to build upon (Friedwichs and Kratochwil, 2009). Consequently, abduction remains the most justifiable approach.

Due to quantitative markers being the most effective way to evaluate the extent of decoupling, this study uses a mono-method quantitative methodological choice (Conte Grand, 2016; Tarabusi and Guarini, 2018). A quantitative marker is more useful than, for example, interviews, which are less appropriate in determining the relationships between environmental and economic outputs, as these variables are provided in the form of quantitative data.

This paper uses a sectoral study due to the inconsistent results seen in most sectors and nations, where there are huge differences in decoupling performance (Naqvi and Zwickl, 2017; Tarabusi and Guarini, 2018). It is therefore difficult within the scale of one study to find what decoupling has occurred and why between sectors of an economy. However, with finer-grained research, one can map out this variation, demonstrating where and potentially why decoupling has or has not occurred, potentially improving the methodology's relevance for policy research and disentangling the complex picture that is currently seen in the literature (Conrad and Cassar, 2014).

This research focuses on the transport sector, where less previous research exists, and on the UK context, where data are more freely available. This matches the aims of the pragmatic philosophical position as it focuses on the practicality of using a case that is best suited to meeting the aims of research. Most discussions on decoupling have taken place within the context of OECD countries and China. However, because of the limited availability of data from

China translated into English, a study on China was not possible for these authors, but is an important area for further research. Previous academic research is primarily focused on OECD countries where studies are more pertinent and feasible (Fritz and Koch, 2016). However, only the UK has suitable data for consumption-based variables, which is discussed in section 2.2, as well as the accessibility of academic and grey literature in English (Barrett *et al.,* 2013). Although rata data is available for other countries through databases such as the Eora MRIO project, this paper required data to be extracted from an input-output source. Nevertheless, this study acknowledges the limitations of just focusing on English-language literature and data sources. The UK also has a wealth of literature on the sustainability of transport but few direct analyses of the relationship between economic output and sustainability (Goulden *et al.,* 2014). As such, this research contributes to filling a much under-researched gap on the application of decoupling analysis to the transport sector, particularly in OECD countries.

Due to the nature of decoupling analysis, the research adopts a longitudinal approach, as the decoupling analysis index measures change in decoupling over time (Schandl, 2016). The study focuses on the period 1997-2015, as this matches the timeframe of data availability and the start of the New Labour Government, where sustainability was intended to be placed at the front of transport policy (Department for Environment, Food and Rural Affairs (DEFRA), 2018).

The method of analysis is decoupling analysis, which takes economic and environmental variables to create a new metric that can elucidate the relationship between environment and growth with one index (Grand 2016). The metric will increase to show a stronger separation of environmental ‘bads’ from economic ‘goods’, or a higher magnitude of decoupling and vice-versa creating an easy to understand index.

2.2: Methods

Table 1 summarises the variables by placing them into economic and environmental categories. For environmental variables, consumption-based emissions most accurately capture the footprint of UK transport, as production-based inventories omit the global displacement of emissions (Davis and Caldera, 2010).[2] This choice also reflects one of the aims of the paper to demonstrate more policy-oriented analysis. It is important to accurately capture UK emissions as production-based estimates are too optimistic for developed countries where emissions are displaced, which therefore provides a weak evidence base to explore the policy responses required for green growth (Peters and Hertwich 2008; UK Statistics Authority, 2018). The chosen variables are shown in Table 1.

Table 1: Environmental and economic variables used in the decoupling analysis

	Environmental Variables	Economic Variables

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[2] The other primary indicator is Technology-Adjusted Balance of Emissions Embodied in Trade (TBEET), which calculates differences between energy systems and technological potential to show where specialisation may cancel out displacement, preventing over-estimation (Jiborn *et al.,* 2018). However, results from the study by Jiborn *et al.* (2018), which created this indicator, do not show differences above 4% between TBEET and consumption in the UK. To create a TBEET based inventory would require fine grained data which is beyond the scope of current resources, without considerable time to attempt to extract them from a input-output database such as Eora, as was done to create the database used in this paper (DEFRA, 2018).

Variable	Consumption-based Greenhouse Gas Emissions	Transport Output
Measure	CO_{2e} (Carbon Dioxide Equivalent)	Passenger-Kilometres, Tonne-Kilometres, Net Mass Movement
Data Sources	DEFRA (2018), Scott *et al.* (2013)	ICAO (1998-2016), UKAO (2018), OECD (2018), UNCTAD (2004-2018), CCC (2010)

This paper uses the metrics of passenger kilometres, freight kilometres and net mass movement as the primary economic variables (see table 2 for definitions). As the purpose of transport is to carry mass over space, simply focusing on passenger and freight mass statistics would not encapsulate the purpose of travel. It should be noted that all modes of transport except maritime transport have both freight and passenger statistics. Maritime transport only includes freight because no international passenger-kilometre data were available. Furthermore, it comprises a negligible fraction of maritime transport, so the omission should not significantly affect results (ITF, 2017; International Council on Clean Transport (ICCT), 2017; Department for Transport (DfT), 2017). Table 2 presents the metrics and calculations for the economic variables in the analysis. These statistics are necessarily broad, to capture the wide range of data sets and activities which comprise the data behind each variable. For example, not all passenger and freight kilometres are equal such as long-range flight which can be more efficient than short. Furthermore, the dimensions and density of freight can affect its efficiency. Consumption-based emissions are also reliant on assumptions which creates variation between assessments of UK transports footprint (Barret *et al.* 2013). These variations are small, but emphasise how consumption-based emissions inventories are more complex to create that their production-based counterparts.

Table 2: Economic variables: metrics, calculation and use in the analysis

Metric	Calculation	Usage
Passenger Kilometres	1 passenger carried 1 kilometre	Passenger-only Statistics
Freight Kilometres	1 Metric tonne of freight carried 1 kilometre	Freight-only Statistics
Net Mass Movement	Freight Kilometres x (Passenger kilometres x Average UK Weight in each year)	Aggregate Statistics

Figure 3 highlights the variable options for decoupling analysis. This research focuses on transport dematerialisation, the decoupling of transport output and emissions, on a theoretical level since the value of transport is beyond GDP. Mechanised mobility is a necessary part of society, not just for economic value, but also for various essential socio-cultural factors; examining GDP undervalues transport, hence making output more suitable (Givoni and Banister, 2013).

Furthermore, since transport policy is focussed on shifting supply and demand of transport output rather than GDP (International Energy Agency (IEA), 2017b), this variable aims to improve the policy-relevance of this research. However, the main difficulty with conducting analysis of transport decarbonisation is the problem of accounting for transport in GDP. Rather than accounting for transportation taking place when using 'own vehicles', it is transportation that is rented by people who perform an activity which is usually accounted for.

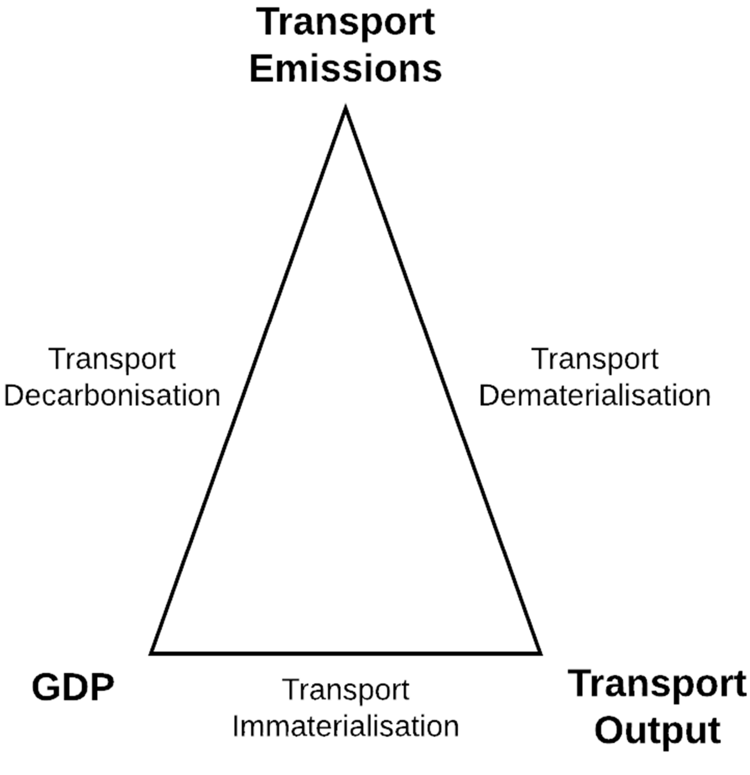

Figure 3: Decoupling variable options
(adapted from Tapio *et al.,* 2007)

The main sources for consumption-based emissions are government statistics, Eora data and a paper by Druckman and Jackson (2008; DEFRA, 2018; Eora, 2013). Only Eora and official statistics have a time-scale above 10 years with raw Eora data not being viable due to constraints outlined in section 2.2, footnote 1. Therefore, one of the few suitable sources was government data, which are considered experimental (DEFRA 2018). As Peters *et al*. (2011) argues, this is not necessarily the case in developing countries where there is an exporting of emissions to importing wealthy nations. For future predictions, one consumption-based source exists (Scott *et al.,* 2013). These data are produced by the same team who are responsible for government historical statistics in the UK and although some estimates must be made, they are consistent with historical data (Sco*tt et al.,* 2013).

This study chose the OECD for road and rail statistics as it is the only source which has converted road transport from the ‘nationality principle’ to ‘territorial principle’ (OECD, 2018a; OECD, 2018b). The nationality principle means statistics are based on where the vehicle is registered. Since this research aims to examine UK consumption, it was imperative to gain data based on emissions used for UK consumption, regardless of where the vehicle was registered. Although Eurostat has data available, it does not have a sufficient time-scale, only going back to 2006 (Eurostat, 2017).

For aviation, this paper used data from the International Civil Aviation Organisation (ICAO). ICAO data also uses the nationality principle, with the only converted statistics being aggregated EU-28 European flight data from Eurostat, which notes the difficulties of gaining non-estimate territorial data (Eurostat, 2018; Eurostat, 2016). Following Eurostat procedure, which is in-line with most statistical guidelines of this kind, estimates were created by taking global passenger-kilometres and finding the UK output share through UK airport traffic (Eurostat, 2018).

A similar procedure was used for maritime transport, as only aggregate global data exists (United Nations Conference on Trade and Development (UNCTAD), 2004-2017). Global freight-ton miles were converted into tonne-kilometres for comparability with other modes, then divided by the share of traffic in the UK (DfT, 2018d). Data were acquired online, except for ICAO statistics, which came from physical copies of their annual report (ICAO, 1998-2016). Table 3 summarises the economic data sources.

Table 3: Economic data sources

Transport Mode	Passenger Data Source	Freight Data Source
Road	OECD (2018)	OECD (2018)
Rail	OECD (2018)	OECD (2018)
Aviation	Converted from ICAO (1998-2016) and DfT (2018a)	Converted from ICAO (1998-2016) and DfT (2018a)
Marine	N/A	Converted from UNCTAD (2004-2018) and DfT (2018b)
Future Growth Scenario	CCC (2010)	CCC (2010)

Future estimations of transport growth were taken from estimations in the Committee on Climate Change's (CCC) 4th carbon budget report, which forecasts transport output to 2030, and then extrapolated to 2050 (CCC, 2010). This extrapolation was undertaken as the report indicates there is no reason to believe that transport growth will cease, assuming that the current growth model for the economy, as well as the trends, remain the same in the 5th carbon budget (CCC, 2010; CCC, 2016). Miscellaneous statistics of car registration numbers, fuel consumption and electric car usage were also taken from UK Government sources (DfT, 2018b; DfT, 2018c).

Looking at different decoupling indexes, Tarabusi and Guarini (2018) argue that many have methodological flaws due to not satisfying a series of axioms (table 4). The most critical of which is how in low growth or degrowth scenarios, other indexes become unstable and do not display metric homogeneity, where changes in the index value always have the same change in variables values. For example, an index-increase from 0.1 to 0.2 should lead to the same increase in variable values as 1.1 to 1.2. The axiomatic method sets out a series of axioms for their index (*Dn*) to make decoupling analysis mathematically sound and comprehensible, shown in table 4 with the problems that each axiom solves (Tarabusi and Guarini, 2018).

One of the original methodological contributions of this research is to add a new axiom, which aims to increase its relevance for policy research, which differentiates between absolute decoupling and relative decoupling. Tarabusi and Guarini (2018) show decoupling performance in terms of the relative difference between the rates of emissions and economic growth (relative decoupling), but it cannot show when there has been an absolute reduction in emissions (absolute decoupling). Without being able to distinguish between an absolute reduction in emissions from simply a slower rate of growth compared with economic variables, the essential component of green growth that decoupling creates, namely an absolute reduction in emissions, is not considered (IPCC, 2014). However, Tarabusi and Guarini (2018) mathematically prove axioms 1-3 cannot be satisfied whilst distinguishing this. This is supported with reference to the OECD (2011), which claims policy relevance is reduced by adding a requirement for interpretation of the index beyond simply seeing an increase as equalling progress.

Whilst parsimony is important, the relevance to policy is impacted more from not distinguishing between absolute decoupling, so interpretation is required where necessary. Furthermore, one can simply look at the decoupling index value only for the presence and magnitude of decoupling if determining whether or not absolute decoupling has occurred is deemed not to be essential. It can also be argued that using these six cases makes the usage of *Dn* redundant against, for example, Tapio's index which uses these cases and can also distinguish three forms of decoupling (absolute, relative and recessive) compared to just two in the case of *Dn* (Tapio 2005). However, there is still much gained from using *Dn* as it preserves important axioms such as unrestricted domain, monotonicity and continuity which other indexes do not.

Table 4: Decoupling axioms (Tarabusi and Guarini, 2018) *= new axiom

Axiom	Problem without Axiom	Axiom Description
1. Unrestricted Domain	Artificially limits situations where index is usable	Index can take a value for any possible combination of values
2. Continuity	Index as values can jump, despite a lack of jump in the corresponding variables	There is no jump in index values
3. Strict Monotonicity	Green growth, where emissions decrease, and output increases is indistinguishable from brown degrowth, with output decrease and emissions increase	An increase in index value must equal and increase in output and a decrease in emissions
4. Unbounded range of values	See axiom 1	There is no limit to index values
5. Metric homogeneity	See axiom 2	Like differences in values equals like differences in index
6. Cumulatives	Forces user to choose arbitrary time-period, which can warp results and damage comparability	The index value for a certain period equals the sum of component sub-periods
*7. *Differentiation of Absolute decoupling*	Cannot show when emissions decrease, which is an essential part of sustainable development	Index can show whether there has been an absolute decrease in emissions

Another original methodological contribution of this research is the inclusion of planetary boundaries as a marker of successful decoupling, in this case, climate change. Planetary boundaries are various environmental limits which mark the safe operating space for humanity in its environment (Rockström *et al*. 2009; Stoknes & Rockström 2018). To do this, a consumption-based emissions scenario to stay within 2^{O}C is set against historical decoupling and future scenarios (Scott *et al.,* 2013; CCC, 2010). Although the conventional metric for this boundary is the concentration of greenhouse gases in the atmosphere, for this study, temperature change is used as a representation of greenhouse gas concentration. The rationale for this choice is to better reflect ecological-economic links with policy, as it better integrates natural systems into the analysis to measure sustainable development.

2.4 Analytical approach

This sub-section outlines the process for undertaking the decoupling analysis. First is the rate of environmental change (*e*) and economic change (*o)*. Subscript *t* and *b* denote the target and base year, which are then compared to show change between these years. To calculate the axiomatic decoupling index, one finds the difference between the logarithm of economic and economic change, as shown in Formula 1:

$$Dn = \tilde{o} - \tilde{e}$$ Formula 1

The above variables are calculated by finding the logarithm of the difference between a target year and base year, as shown below:

$$\tilde{o} = \log(O_t / O_b)$$ Formula 2

$$\tilde{e} = \log(E_t / E_b)$$ Formula 3

The *Dn* values are then added to calculate aggregate figure for each mode of transport, a total figure for all modes and future decoupling requirements with different growth scenarios. The index values are placed onto a cartesian plane to visually compare the results, with emissions (ẽ) on the x axis and output (õ) on the y axis to show the relationship between the two. The diagonal lines show the level of decoupling performance (*Dn*) across different values of ẽ and õ, with units marked on the lines. The plane also shows the methodological soundness of the index, as the lines for *Dn* are equidistant, representing how it satisfies axiom 2, 3 and 5. When *Dn* is >0, there is decoupling, and a higher value represents an increasing magnitude of decoupling.

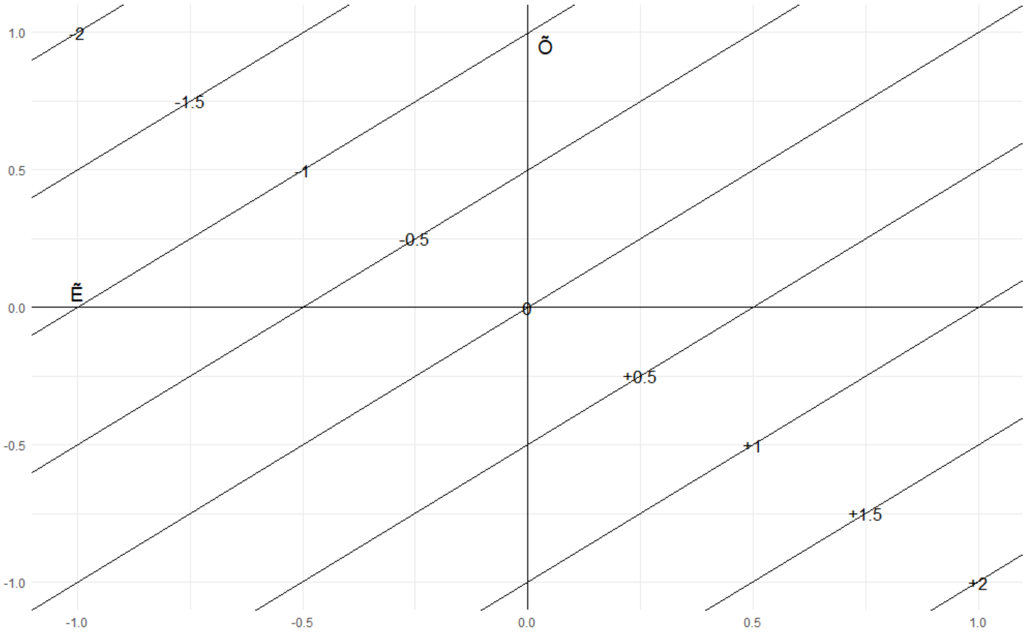

Figure 4: Example Cartesian plane with lines representing D*n* values

To increase the detail on the type of decoupling that is occurring, these can be defined into six cases, following a similar format to cases outlined for other indexes (Conte Grand, 2016). This detail is necessary to satisfy axiom 6, which aims to improve its relevance for policy research by providing greater detail. *Relative decoupling* occurs when there is both a growth in emissions and output, but output increases at a faster rate. *Absolute decoupling* denotes growth in output, but a decrease in emissions. *Recessive decoupling* is still decoupling, as emissions decrease at a faster rate than output, but both are negative. There are then three types of *negative-decoupling*, which occur when emissions are emitted at a faster rate than output. Firstly, *expansive negative-decoupling* refers to a situation where both are increasing but emissions increase at a higher rate. Secondly, *relative negative-decoupling* refers to a decrease in both emissions and output but emissions are decreasing at a slower rate. Thirdly, *absolute negative-decoupling* refers to a situation where emissions are increasing but output is decreasing.

Table 5: Decoupling scenarios

$\tilde{e}$	$\tilde{O}$	$\boldsymbol{Dn}$	Decoupling	Economic State
>0	>0	>0	Relative Decoupling	Growth
<0	>0	>0	Absolute Decoupling	Growth
>0	>0	<0	Expansive Negative-Decoupling	Growth
<0	<0	>0	Recessive Decoupling	De-Growth
<0	<0	<0	Relative Negative-Decoupling	De-Growth
>0	<0	<0	Absolute Negative-Decoupling	De-Growth

3. Results:

3.1 Aggregate and Total Results

Figure 4 presents the total and sector-based aggregate decoupling figures over the study period. The scale of the graph was selected based on a comparative study of the UK's decoupling from 2003-2017 with the highest index result being 1.1, therefore encapsulating the realistic scope of decoupling possibilities (Tarabusi and Guarini, 2018). It demonstrates a lack of decoupling throughout each mode, as the highest magnitude result is 0.13 from rail with *relative decoupling*. Therefore, no significant change has occurred across the sector.

All sectors except maritime transport achieved decoupling during the study period. However, only road transport achieved *absolute decoupling*. Modal index results show *low magnitude relative decoupling* at 0.014. Aviation also achieves similarly negligible index results at 0.03. Maritime transport displays the opposite trend with *absolute negative-decoupling* at -0.36.

Observing total trends over time, the largest drop in emissions relative to output was 2007-2009 around the 2008 financial crash. Before and after this period, there is mostly *low magnitude relative decoupling* or *negative-decoupling*. This fluctuates with no clear trend both up until, and after, the 2008 financial crash, except an increase in emissions towards the end of the study period.

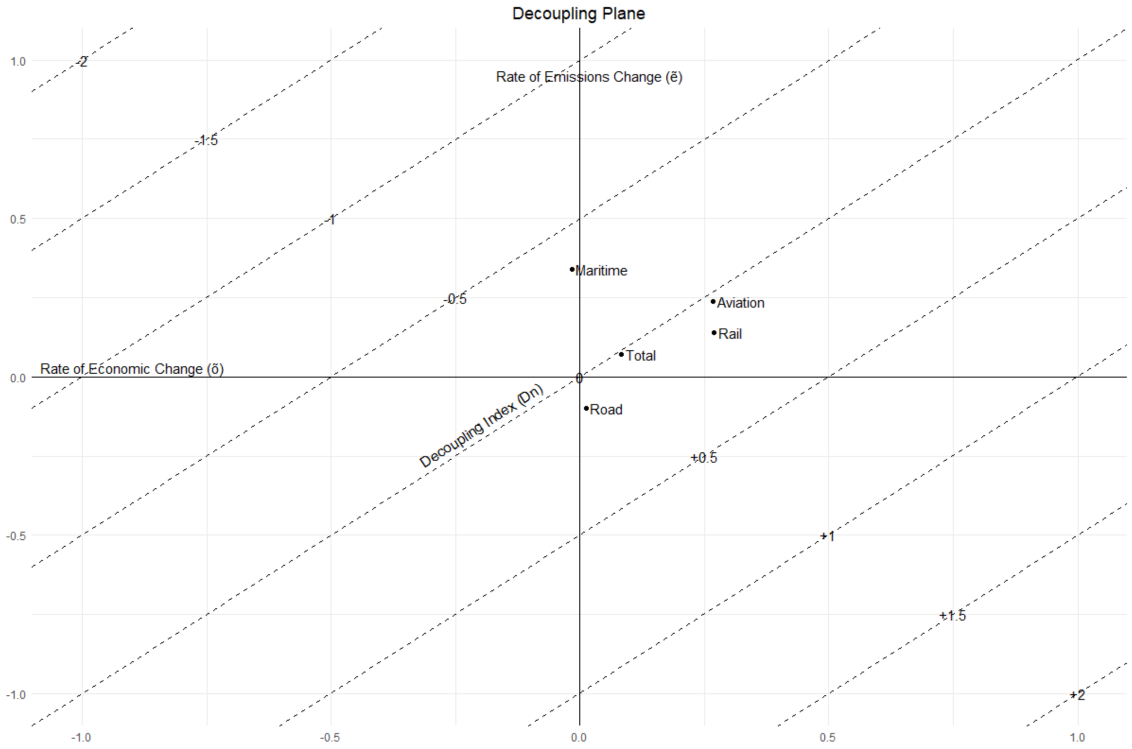

Figure 5: UK transport decoupling

3.2 Modal Comparison

The modal index results, however, do not consider the contribution of each sector to the total decoupling. Figure 5 shows the changes in emissions over time to elucidate modal contributions to overall results. According to production-based government statistics, road transport was by far the largest contributor to emissions. However, when using consumption-based emissions this is no longer the case (DfT, 2017). Aviation and maritime transport have increased their share of emissions, with aviation becoming the largest emitter in 2008, though maritime transport is to a lesser extent contributing to the recent overall lower decoupling rate since the 2008 financial crash. It also shows a much larger proportion of emissions being attributed to aviation and maritime transport than in production-based inventories. It appears that, given the small magnitude of rail transport and the increasing inefficiency of aviation and maritime transport, road transport has primarily driven the positive total decoupling observed.

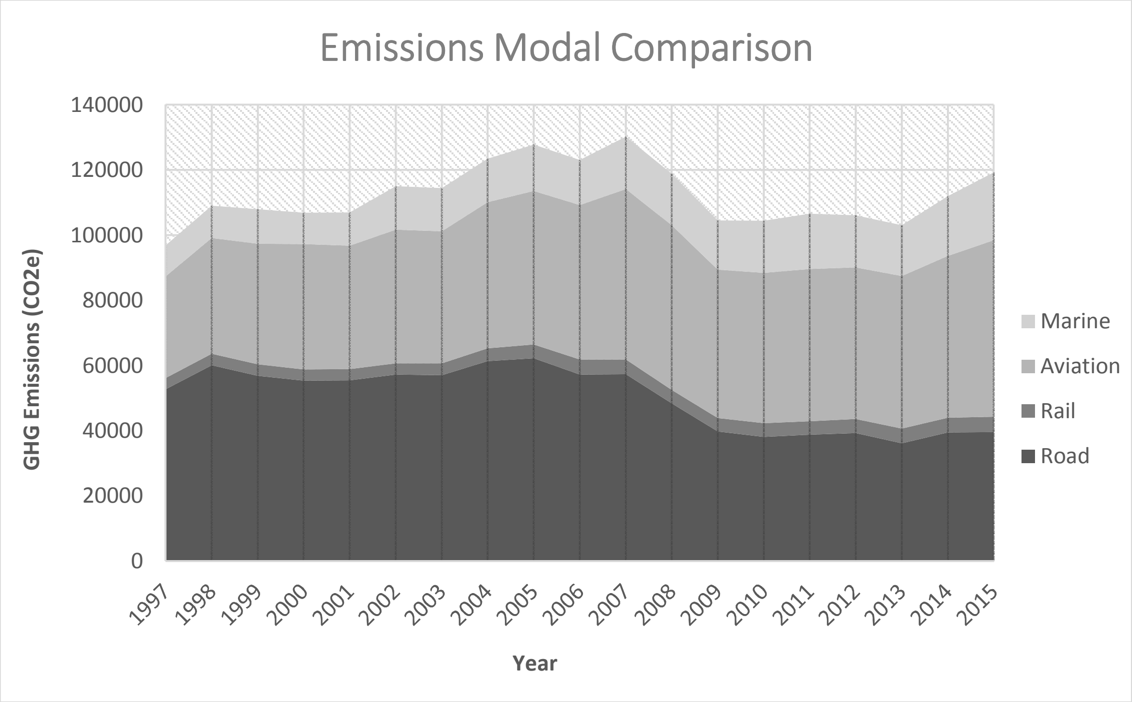

Figure 6: Comparison of greenhouse gas emissions across different transport modes

Road transport's role in decoupling becomes clearer when comparing modal output, as road transport has remained steady throughout this period, whilst emissions have dropped. Rail transport shows little contribution to overall results, despite reporting the highest magnitude of decoupling. As discussed in section four, marine transport and aviation transport have shown minimal decoupling, as there has not been a substantial enough increase in output, as shown in Figure 6.

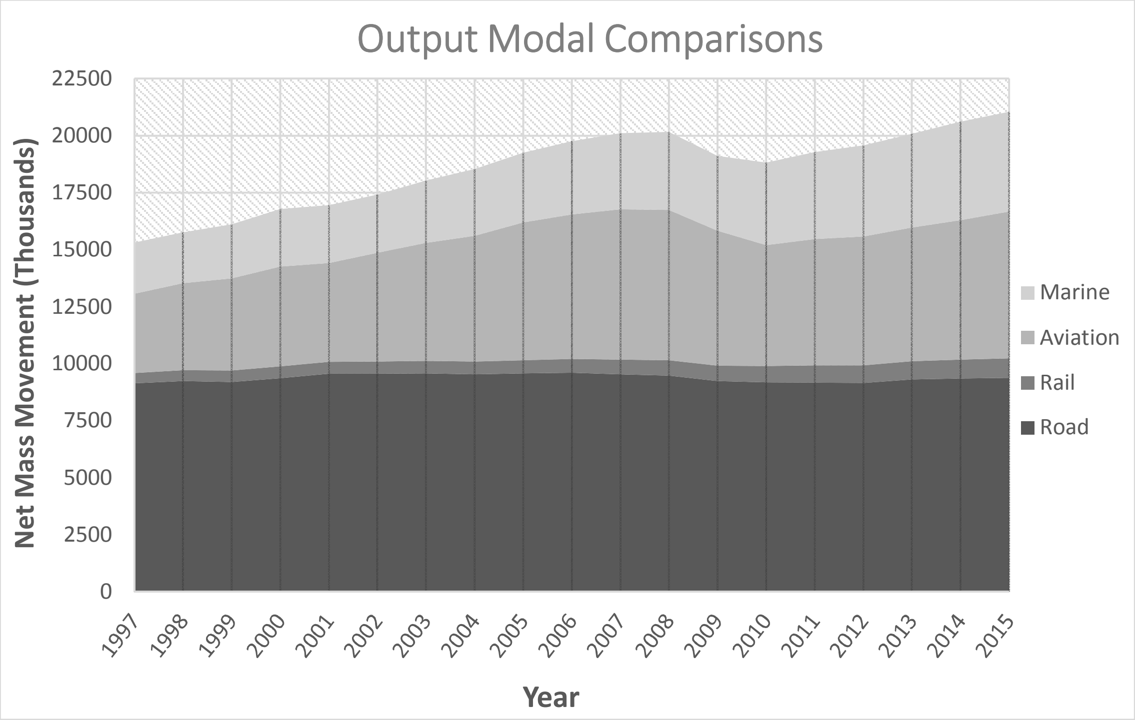

Figure 7: Comparison of mass movement by different transport modes

3.3 Modal Trends

With the exception of the large decrease in emissions during the 2008 financial crash, little has changed during this period for road transport with *low magnitude decoupling* and 8 out of 15 years involving *negative-decoupling*. *High magnitude absolute decoupling* during the 2008 financial crash led to the aggregate index result showing *absolute decoupling*.

With regards to rail transport, *relative decoupling* occurred in the late 1990s, which then coupled, before a period of *absolute* and *high magnitude relative decoupling* from 2007 onwards. The 2008 financial crash had a much smaller impact on rail transport than any other transport mode and it is the only one to show continual improvements outside of sudden shocks.

Aviation transport was the most sensitive to the 2008 financial crash with a severe decrease in output, contrasted by continual growth throughout the study period. Compared to rail transport and road transport, however, there is the opposite trend with regards to efficiency with *high magnitude relative decoupling* collapsing and almost a complete coupling of emissions and output by 2010 due to *high magnitude absolute negative and relative negative-decoupling* at different times. Following this, there were some indications of *relative decoupling*, albeit narrowing in the last three years of the study period. However, the 2008 financial crash had the largest impact on aggregate results, masking otherwise relatively *high magnitude decoupling* compared with road transport and maritime transport in most years.

Maritime transport has *absolute negative-decoupling* in all but three years in the study period. Despite this, these results may be higher than in reality: accounting for 'slow steaming' (whereby ships move more slowly to reduce emissions) in recent production-based inventories has led to revised lower emissions since 2010 (DEFRA, 2010). No consumption-based inventory has included this revision as far as the authors are aware. However, even assuming *relative decoupling* for recent figures, there would still be *negative-decoupling*, as Scott *et al.* (2015) notes that the efficiency gains from slow steaming are small. Production-based statistics also follow similar trends to the ones shown here, supporting the output data used for this research (DfT, 2017). Moreover, the 2008 financial crash caused rec*essive decoupling.* Without this, the aggregate results would show even greater *negative-decoupling*.

3.4 Future Scenarios and Planetary Boundaries

With future scenarios, the challenges of decoupling can be placed within planetary boundaries. Emissions in the study period have made little progress towards necessary decoupling. Even with degrowth of 0.5%/yr, much *higher magnitude absolute decoupling* is required to meet the goal of limiting temperature increases to ‘well-below’ 2ᴼC, as outlined in the Paris Agreement, which is used here as a proxy for planetary boundaries. With a steady state, and particularly in a growth scenario, the decoupling required is even larger, as shown in Figure 7).

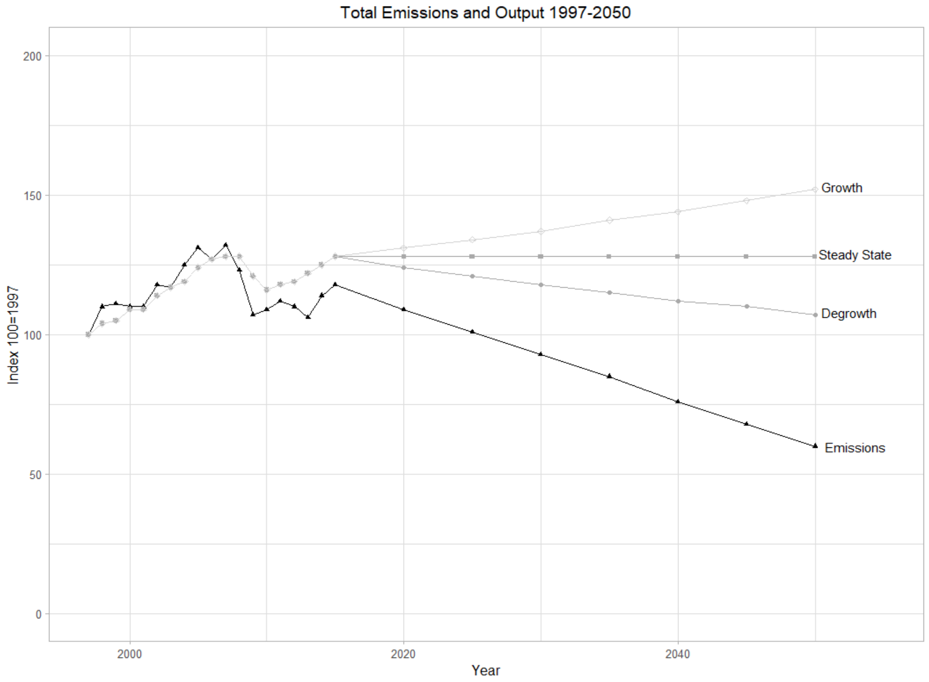

Figure 8: Trends of future emissions and output for the UK transport sector

This can also be represented on a Cartesian plane (Figure 8), where past decoupling is placed against three future decoupling requirement scenarios to meet climate change targets, further highlighting the increased decoupling required to stay within planetary boundaries. All scenarios require *higher magnitude absolute decoupling*, albeit with decreasing intensity towards degrowth, which is within the same broad decoupling boundary of 0-0.25 of historic results.

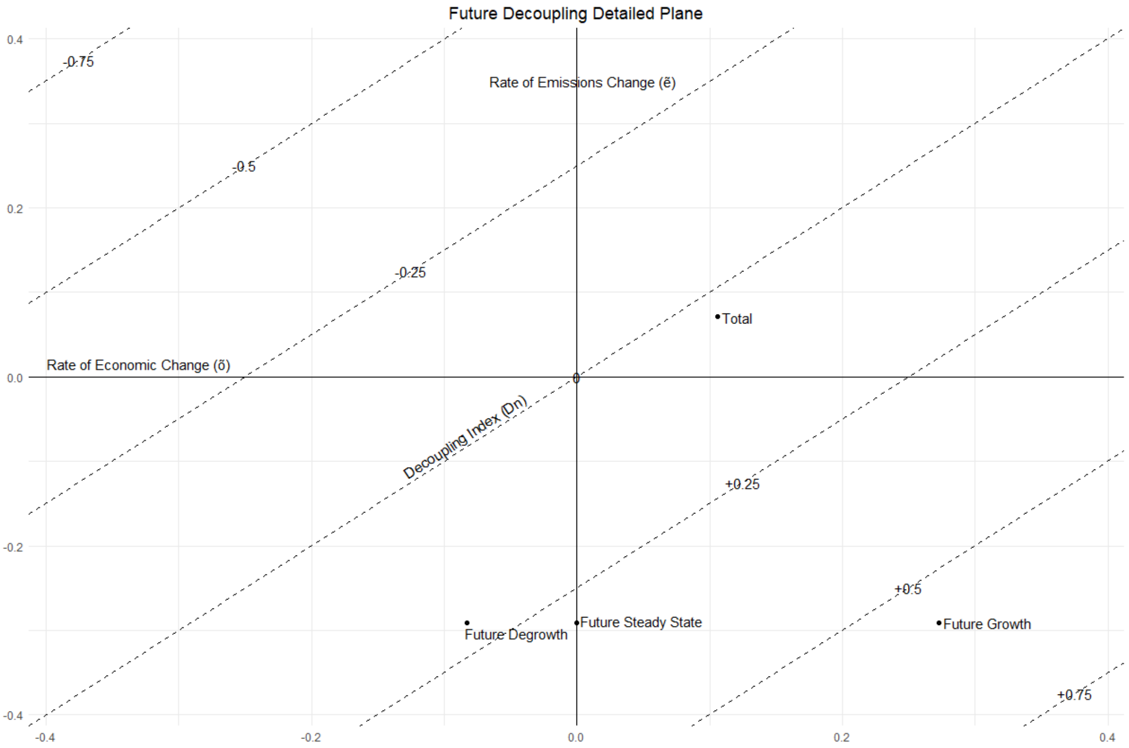

Figure 9: Future decoupling scenarios for the UK transport sector

4. Discussion

4.1. Decoupling Trends

Across the results, short-term economic shocks appear to have a greater impact on decoupling than long-term policy change. For example, road transport shows high magnitude decoupling from 2008-2010, despite stable fuel use and passenger-kilometres, suggesting that efficiency of individual journeys did not change (DfT, 2017 and 2018c). The important factor was instead a reduction in new vehicles purchased and the associated decrease in emissions from material extraction, construction and shipping (DfT, 2018b). The timing of this, combined with no policy measures in the UK to reduce car purchases, suggests it is likely that the decrease in car purchases due to economic circumstances drove decoupling above long-term policy outcomes (Tseng *et al.,* 2013). This short-term effect is even more pronounced for aviation transport, with *high magnitude negative-decoupling* during the financial crash and *low magnitude relative decoupling* afterwards.

Only rail transport shows long-term decoupling over the study period. Nevertheless, it appears there has been a failure to increase supply, despite high demand, consequently contributing to increased car and aviation usage (Davis and Tapp, 2017). As McKay (2008) and Kaack *et al*. (2018) argue, rail transport is more efficient with potential for modal switching from all other transportation. The results for maritime transport also display a similar trend, as it is also more efficient than road or aviation freight but output flatlined. This is particularly problematic as both road and aviation are highlighted in the literature as significantly less efficient modes of transport (Lynn *et al.* 2018).

Aviation and maritime transport have seen little, if any, decoupling. Whilst aviation is witnessing an increase in output and emissions at almost the same rate (20% and 18% from 2010-2015), maritime transport output has flatlined, whilst efficiency has decreased. This *negative-decoupling* in maritime transport could be linked to the lack of efficiency of transport and ports in less-developed countries, as the UK has increasingly imported goods from these less efficient sources (Cristea *et al.,* 2013). Other explanatory factors may include the shipping of more carbon-intensive goods or the rising use of smaller ships, as well as more long-distance trade resulting in higher emissions per tonne-km (ICCT, 2017; Cristea *et al.,* 2013). Graham and Shaw (2008) demonstrate that aviation's increasing output is primarily driven by a significant rise in the availability of cheap flights. Reduced decoupling in recent years makes aviation an even greater issue for green growth due to the aforementioned *low magnitude relative decoupling*. This has been linked by Li *et al.* (2016) to inefficient structures of airlines and an increase in flights on less efficient routes.

Despite these problems, aviation and most maritime transport are not included in national emissions inventories or EU emission-trading schemes, beyond limited areas of aviation, as there has been a failure to find a collectively agreeable solution between industry and governments (Bows-Larkin, 2015). The UK government responded by claiming that the economic effects of accounting for these modes would be too significant and consequently not addressing the resulting environmental pressures from this decision (DfT, 2013). The *low-magnitude relative* and *negative-decoupling* finding reflects the consequences of this outlook, further demonstrating the limited policy leadership to drive decoupling in transport. It remains to be seen whether the new net-zero targets will include these, as recommended in the recent CCC report (CCC 2019).

Across the literature on UK transport, one of the most frequently-recurring conclusions is that the UK Government has yet to move away from the 'predict and provide' paradigm, whereby it focusses on predicting future demand and generally equating this to need. Demand is met by increasing the supply of new infrastructure as much as is financially possible, particularly roads, whilst letting the market and industry drive transport policy (Begg and Grey, 2004; Glaister *et al.,* 2006). These concerns have been cited since the New Labour Government in the late 1990s, which claimed that policy would move to a 'new-realist' approach that integrated sustainability into transport. However, 'predict and provide' has taken precedence until the present day (Davis and Tapp, 2017). The current road building strategy, for example, is committed to the "largest programme of investment for a generation" and this has continued as the primary vehicle for transport infrastructure investment (DfT, 2014, 13 and 2018f). This paper provides further evidence for these arguments, as the short-term origins of decoupling and the lack of overall efficiency gains demonstrate that transport policy has not produced significant decoupling, which is a necessary component of achieving green growth in the transport sector.

4.2 Barriers to Increased Transport Decoupling

Large changes in decoupling are required to achieve sustainability in the transport sector. The lack of policy leadership suggests that decoupling is unlikely to materialise. However, more optimistic areas of the literature often point to technological efficiency gains and stress that the dominant sustainable growth paradigm and current climate policy can deliver decoupling (for example UNEP, 2011; Schandl *et al.,* 2016). However, there are numerous technological and political barriers to deliver decoupling within planetary boundaries, necessitating the reconsideration of its viability.

Nevertheless, technological innovation has brought about some efficiency gains. Aviation transport and maritime transport have seen improvements, such as engine efficiency, port upgrades and fuel technology (Cui *et al.,* 2016; UNCTAD, 2017; Accario *et al.,* 2014). The more positive results seen in rail transport have arisen from similar efficiency efforts, the only examples of long-term progress in this paper (IEA, 2017c). However, whilst it is difficult to track exactly how technological improvement has affected decoupling, the lack of long-term decoupling suggests that it did not cause significant change, necessitating a rapid increase in innovation.

However, Baharozu (2017) argues that for aviation there is no viable alternative fuel at present or possibilities to greatly improve efficiency using current fuels unless a breakthrough is made. Whilst maritime transport has a higher capacity for improvement, shipping comprises an increasing share of transport emissions (alongside *negative-decoupling*) meaning that technological change alone is not sufficient to create necessary decoupling in the UK (Shi, 2016).

Given these issues with aviation transport and maritime transport, the highest potential for decoupling from technology lies with road and rail transport, particularly in terms of fuel consumption. However, Hawkins *et al.* (2012) points out that it remains to be seen whether fuel switching will take place, and other environmental problems from doing so need to be considered, such as emissions associated with battery construction and the shipping of cars from abroad. Therefore, technological innovation is not a panacea, particularly in cases such as aviation transport, where Peeters *et al.* (2016) argue that waiting for this change has repeatedly led to complacency and slower policy action.

The problems of technological limits to decoupling are compounded by political barriers. As discussed above, there are disagreements between different countries and industries over how to account for international aviation and shipping (Bows-Larkin, 2015). Furthermore, the prevalence often given to economic goals hinders policy that could deliver decoupling (for example, the decision to open a new runway at Heathrow Airport in the UK – DfT, 2018e). Gössling *et al.* (2016) also notes that, in interviews with EU policy-makers, the widely-held belief in technological change has contributed to a reluctance to look at behavioural change. There is a wealth of literature displaying how challenging behavioural change is to implement, even with enthusiasm from policy-makers (Chapman, 2007; Barr *et al.,* 2010; Schwanen *et al.,* 2012). Achieving high-magnitude decoupling is very challenging (Gössling *et al.,* 2018). Thus, options need to be considered beyond technological and growth-focussed pathways to more transformative changes. For example, shifting both supply and demand towards more efficient modes such as rail and potentially limiting the growth of currently unsustainable transport such as aviation.

4.3. Key Methodological Considerations

The previous two sections have focussed on substantive conclusions drawn from the analysis. Underlying these results is a policy orientated research design to ask new questions of the transport sector and its ability to meet sustainability targets. The following section considers how key aspects of decoupling analysis research design can potentially be useful for policy-focussed practitioner research, as well as looking towards future improvements.

These considerations include the context of global consumption, *absolute decoupling*, efficiency, the position of researchers, as well as the scope of the study.

Consumption-based international emissions inventories are important, as some aspects of transport are missing in production-based inventories, which the prevailing policy consensus views as acceptable (Afionis *et al.,* 2016). For example, in road transport *absolute decoupling* was only possible due to a change in consumption of vehicles, largely from abroad. Hence, looking at efficiency saving in terms of domestic production is insufficient to fully understand the footprint of the transport sector. This is particularly important to note, as the new net-zero targets being implemented by the UK government are informed by the CCC net-zero report which used production-based metrics, underestimating the challenge to decouple (CCC 2019).

Considering applicability to policy research also reveals a limitation to decoupling analysis, as different measures of ‘success’ can be found. Whilst road transport achieved *absolute decoupling*, the magnitude was 0.011 less than rail transport. It is therefore necessary when using decoupling metrics for policy research to look at what the goal is, whether this is an absolute reduction in emissions or improved decoupling performance. For example, all future scenarios in this paper require *higher magnitude absolute decoupling* but of varying magnitudes. Depending on the economic goal, the importance of magnitude against absolute emissions reductions changes. Furthermore, it highlights the importance of including absolute emissions. Without this, the challenge of future decoupling would not be fully revealed, as the degrowth scenario does not require a large increase in the magnitude of decoupling and the more significant change comes from the shift to *absolute decoupling*.

Overall efficiency is contextually useful for policy research, as it provides a starting point to examine where decoupling is most urgently needed. For example, *negative-decoupling* of maritime transport in the UK does not equal a need to increase road or aviation freight, as it remains the best option for long-distance freight (Creutzig *et al.,* 2015). The example of rail travel also highlights this point, as its high efficiency means that despite *absolute decoupling* of road transport, it would still be better to shift road freight to rail.

The academic literature does not fully acknowledge how being free of the need to create actionable policy can help form their conclusions. An example of these needs would be the use of production-based emissions being largely due to their inclusion in existing national inventories with no resources to effectively account for consumption (CCC, 2013). This is true in the case of this research, where its academic nature allowed methological flexibility to use consumption-based emissions. By acknowledging the reasons behind methodological differences between the academic and grey literature, further research should try to bridge the gap between them by focussing on the practicalities of conducting analysis outside of academia and turning conclusions into actionable policy.

Whilst detail on emissions, reflexivity and overall efficiency is important, it is difficult to provide strong policy conclusions without comparison across modes and sectors where necessary. A wider view into other sectors could significantly alter how results are viewed. Although this study has shown that transport in the

UK may not be able to decouple within planetary boundaries, there is potential for offsetting in areas such as energy or food consumption, where shifts in clean energy and changes in diet can produce significant gains in decoupling (Poore and Nemecek, 2018; Moriarty and Honnery, 2012). Furthermore, this paper is limited to examining transport in the UK. Comparing to other sectors could place the results presented in this paper in a different light. Similarly, these findings may not hold true in other countries with different contexts. Further research is warranted in these areas before one can declare the viability of green growth for UK transport, or the necessity of other action.

5. Conclusion

This paper examined the extent of decoupling between growth in transport and emissions in the UK from 1997-2015. The research developed innovative decoupling analysis techniques and identified how they could be oriented towards policy-focussed practitioner research on transport. These methodological improvements include an axiomatic decoupling index with reformulated axioms and a consumption-based emissions inventory that includes planetary boundaries for the decoupling analysis. The analysis focused on the UK because it contains a wide range of policy debates on transport, but with a lack of empirical analysis underlying the arguments, as well as the important gap in the academic decoupling literature on transport.

The results show that emissions and output in UK transport have experienced *low magnitude relative decoupling* from 1997-2015. This was chiefly driven by absolute decoupling of road transport during the 2008 financial crash, with aviation transport and maritime transport experiencing increased output and emissions with very low magnitude decoupling and negative-decoupling. Future scenarios highlight the important gap in the transport sector between current efforts and future requirements for the UK to contribute towards the ‘well below’ 2^{O}C target outlined in the Paris Agreement. This highlights the challenge of decoupling within planetary boundries and questions the viability of green growth for UK transport, particularly due to the lack of policy leadership and technological barriers. It suggests that more radical changes beyond relying on efficiency, such as limiting more unsustainable transport, may become necessary.

Beyond these substantive conclusions, this research is an example of how the extent of decoupling can help to provide an explicit relationship between economic and environmental change. Furthermore, the proposed innovative methodological approach demonstrates the importance of considering consumption-based inventories, overall efficiency, the positionality of the research and wider contexts.

However, it is important to note that the research does not claim that the proposed methodological approach will necessarily improve policy research, as no model is developed to explain why the academic literature is misaligned with such research. Therefore, further research should investigate the use of academic literature by policy-makers and researchers to determine whether or not the proposed methodological techniques would improve policy outcomes. Greater research is also needed to improve consumption-based emission inventories both in and beyond the UK to create a more accurate picture of the footprint of different countries and the accuracy of decoupling findings. Finally, further research on decoupling axioms would help to reduce the conflict between parsimony and detail for policy-oriented research.

In conclusion, UK transport from 1997-2015 has had low magnitude relative decoupling outside planetary boundaries. Using an innovative research design, insights can be drawn on how to create policy-orientated decoupling analysis.

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- Fills a gap between academic and policy/grey literature on decoupling in transport
- A novel policy-orientated decoupling analysis methodology is developed
- Identifies a lack of significant decoupling in UK transport between 1997-2015
- Decoupling within planetary boundaries requires a large shift from current trends
- Improvements in decoupling analysis for transport policy research are suggested